Fermilab
PPD/MD/Engineering Analysis Group

A Recent Stress and Stability Study for the RPVC Structure Used in a Liquid Scintillator Detector

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The Vertical Cell

As an earlier study(1) indicated, the stress at the vertical cell is about 5,300 psi for 2 mm wall. Compared with a recent inquired material RPVC 7181 from Georgia Gulf, the safety factor against yield is SF=Sy/Smax=1.15. The minimum SF is required to be 1.5, which is equivalent to use 2/3 of the yield stress as its allowable.

With an updated geometry, a 90-degree corner has been modified to a 3 mm chamfer or 1/8" radius fillet as shown in Figure 1. The Ansys shows that the stress has been improved from 5,300 psi to 3,900 psi for both 3 mm chamfer design and 1/8" radius fillet designs as shown in Figure 1. The difference between the 3 mm chamfer and 1/8" radius is negligible.

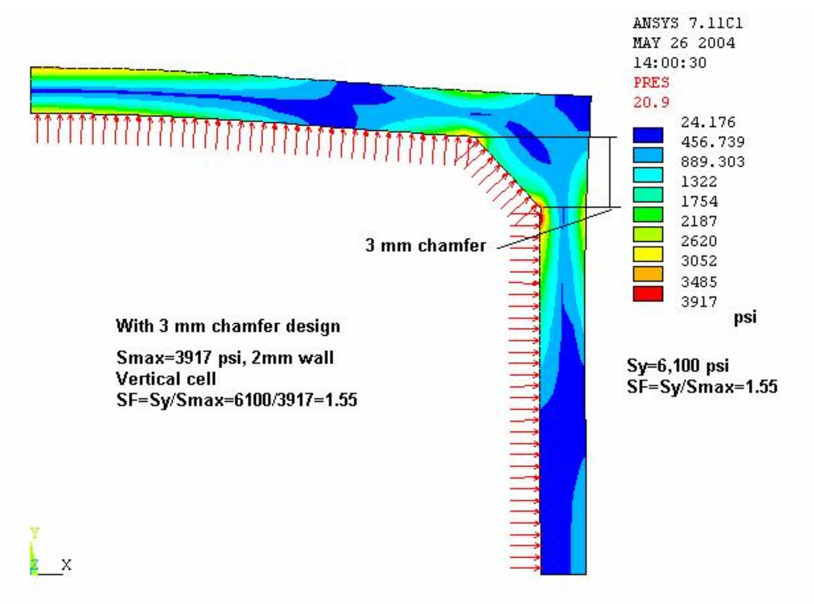


Figure 1 (a)The stress resultant for the vertical cell with 3 mm chamfer

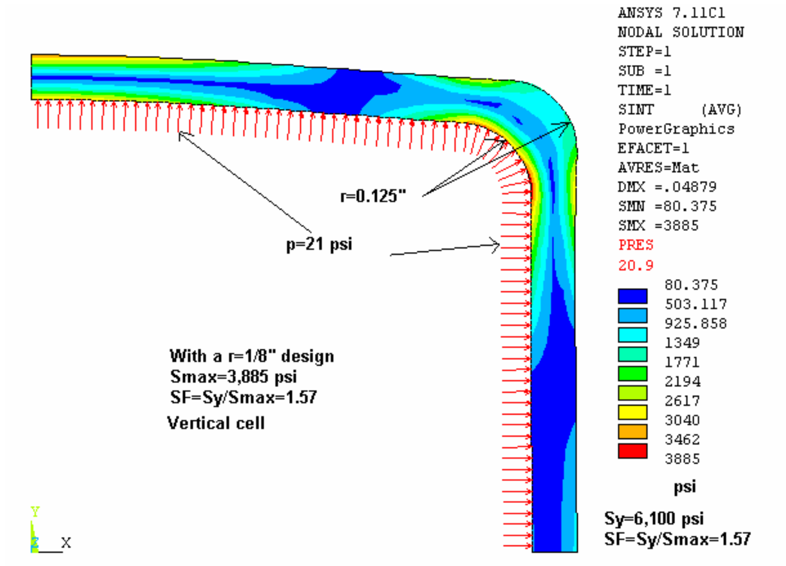


Figure 1 (b)The stress resultant for the vertical cell with 1/8” radius fillet

The Horizontal Cell

Since the horizontal cell is loaded with both a hydrostatic load within its own module and the gravitation load from top modules as a compressive force, two calculations have been done. One is to check its stability against the lowest cell buckling, and second one is to calculate the working stress against the material yield. The buckling calculation has been done with an assumption that the cell has 1.5 psi hydrostatic pressure around with a compressive force from top structure as a 22.3 lb/in, which is calculated as

1000 kg/module * 14modules* 2.2/(689”*2 sides)=22.3 lbf/in

This is probably a worst scenario. The eigenvalue solution from ANSYS shows a safety factor of 3.3 against the buckling as shown in Figure 3. This approach servers as a quick assessment only as stated in reference 2. As a further improvement, a non-linear large deflection analysis is carried out by increasing the load up to a point where the structure starts losing its load carrying capacity. The load verse displacement curve in Figure 4 reveals that the cell is very stable up 57 lbf/in. Then, it starts to curve up to 68 lbf/in. Any small load increased beyond that point would cause a very large or infinite displacement. If we used a 64 (lbf/in) as an average value for Pcr, SF will be 64/22.35=2.9. It is about 90% of SF= 3.3, calculated by eigenvalue method. Therefore, we do have some confidence about its stability calculation. A closed form solution[(3)] has also indicated the SF being more than 3 as shown in Appendix A.

The stress calculation for the horizontal cell shows that the maximum stress is less 700 psi under the operating condition.

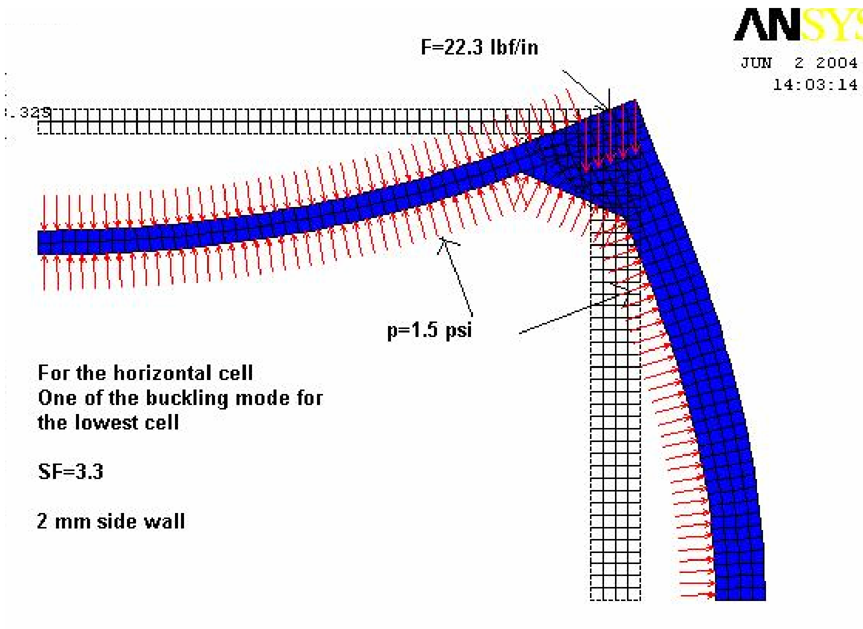


Figure 3 The buckling calculation based on eigenvalue approach

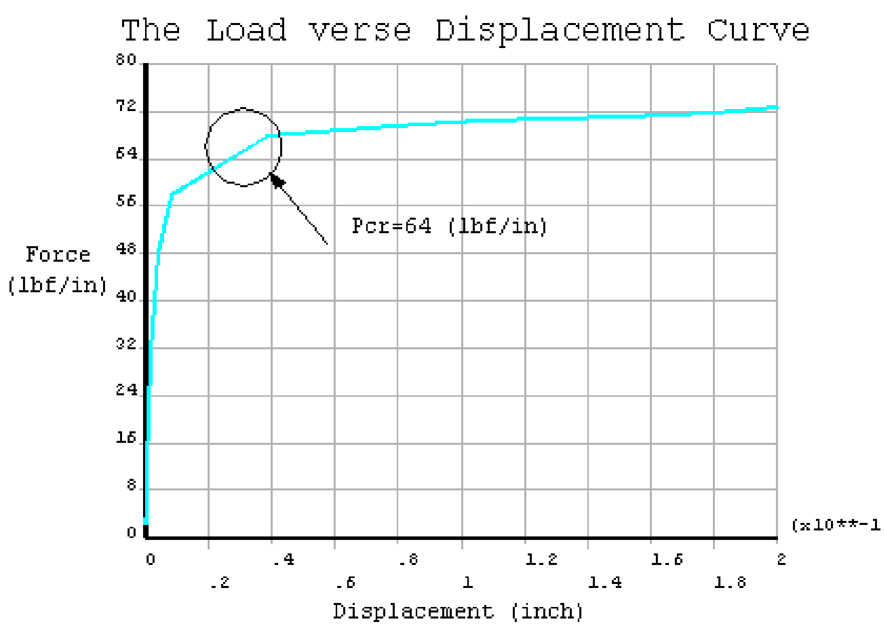


Figure 4 The buckling study based on a non-linear analysis

Gluing the Vertical and Horizontal Cell Together

The structure of the liquid scintillator is to have a horizontal plane and vertical plane alternated each other as shown in Figure 5. As a possibility, these two planes could be glued together. it is very interested to know how much strength it will carry. As an earlier study indicated, the maximum stress for the vertical cell is about 3,300 psi if it stays as a single plane. It is very close to its limit in terms of the safety factor. With a creep curve becomes available later, SF will be certainly brought down more or below to

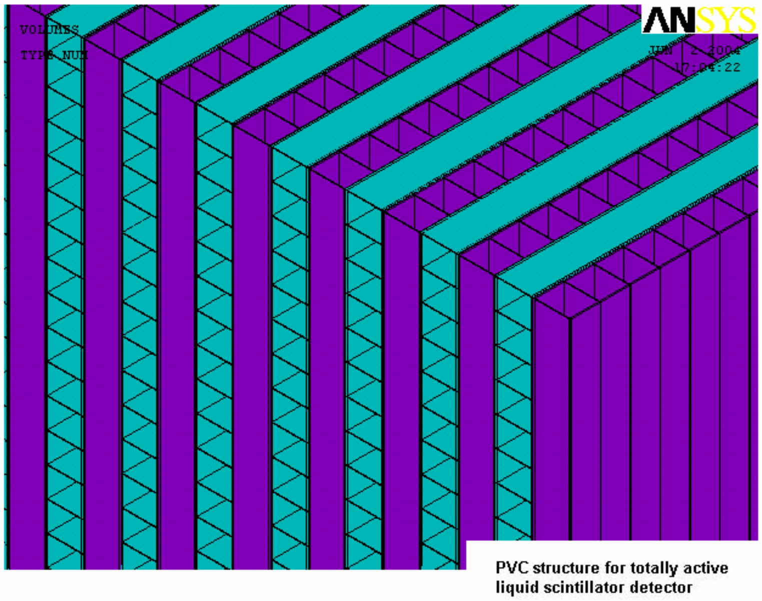


Figure 5 The proposed PVC structure [4]

1.5. Therefore, it may be desirable to look at so called "a combined strength" of the structure. By assuming they are glued together without any slippage as shown in Figure 5. The initial calculation shows that the divider in horizontal cell will be buckled first before the sidewall. We've understood that mode is probably impossible due to the fact that the vertical cell divider is indeed in tension while the horizontal divider is in compression. Having one side is in tension while the other side is in compression, the buckling chance for the divider is none as long as the tension side stress does not exceed its yield. The calculation shows the maximum tensile stress for the vertical divider is about 800 psi, which is well below to its yield. As a result, a simplified calculation is done by eliminating the divider for both vertical and horizontal cell. The statement is made that what safety factor SF will be for the buckling and working stress for a 4 mm wall. The Ansys calculation shows that the safety factor SF is more than 20 against the buckling and SF=6 against the yield for its working stress as shown in Figure 7 through Figure 9. Two planes gluing together does offer : (a) to increase the buckling capability (b)to reduce the working stress.

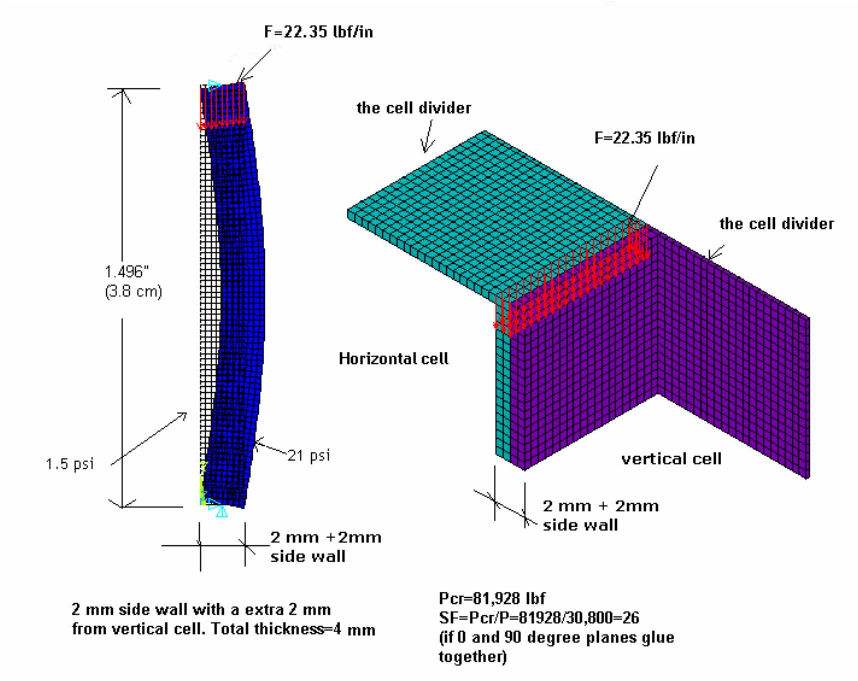


Figure 7 The Case for the gluing two planes (vertical and horizontal)

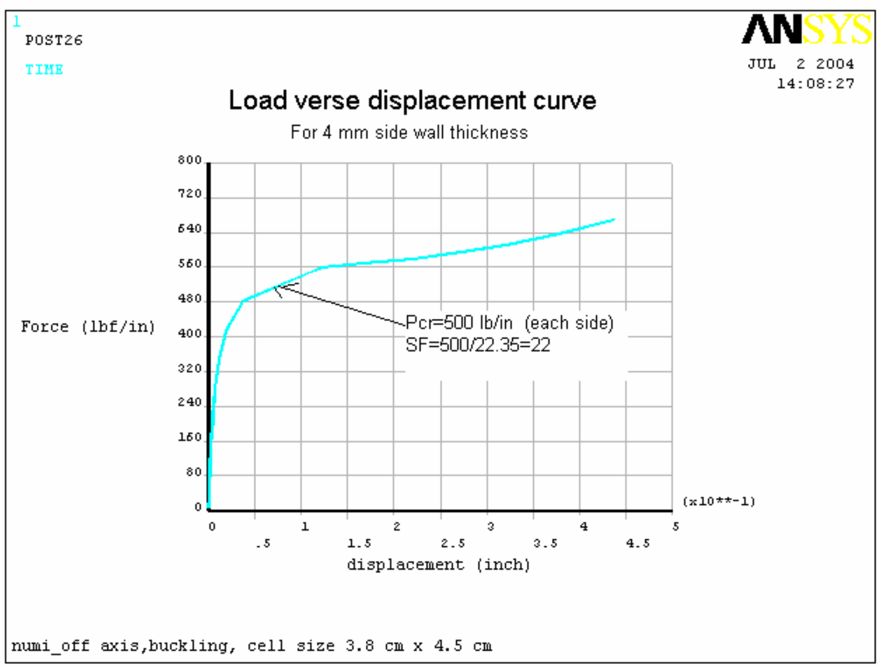


Figure 8 The collapsing force Pcr based on the non-linear Analysis for a 4 mm sidewall

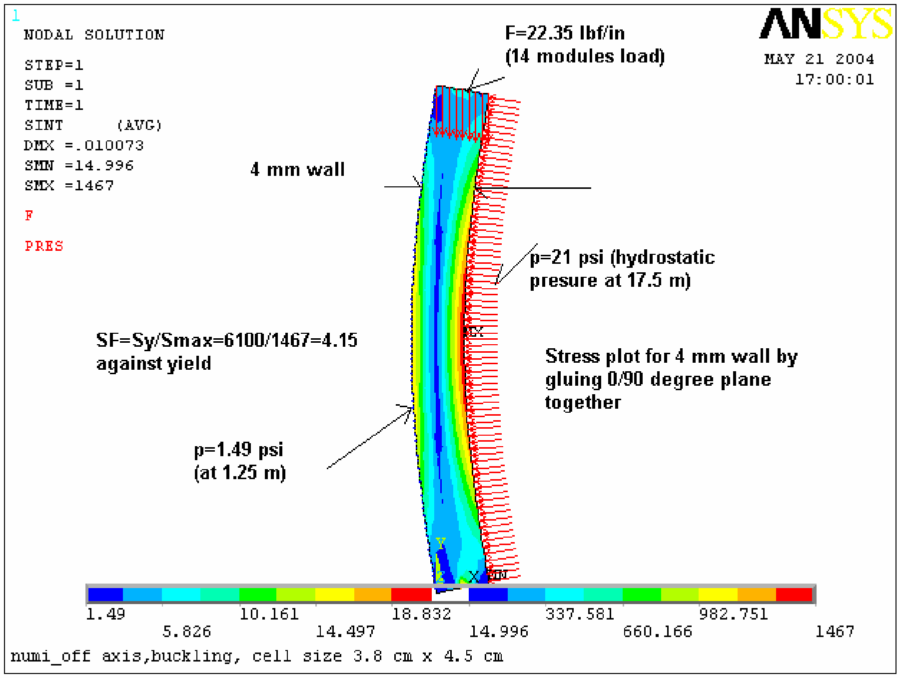


Figure 9 The working stress for the case of gluing 0/90 degree planes together

<u>Reference</u>

1) Ang Lee: "A Preliminary Stress Calculation for the Cell Structure Used in Liquid Scintillator (Off-Axis)", #MSG-EAR04-352, Fermilab Feb24, 2004
2) ANSYS Inc: "Structure Analysis Guide &Chapter 7, Buckling Analysis" Version 7.1
3) Timoshenko & Gere:" theory of Elastic Stability", Second Edition, McGraw-Hill, 1988, pp62
4) Stan Wojcicki: "An Alternative Version of a Liquid Scintillator Detector: Totally Active Configuration", Stanford University, Off-Axis-Note-scint-28,Feb.21, 2004

<u>Appendix A</u>

Pcr is calculated based on "Theory of Elastic Stability" by Timoshenko, 2nd Edition, pp 62.

Buckling of frame:

$$\frac{\tan u}{u} = \frac{-Ib}{I_1 l} \quad \text{(b)}$$

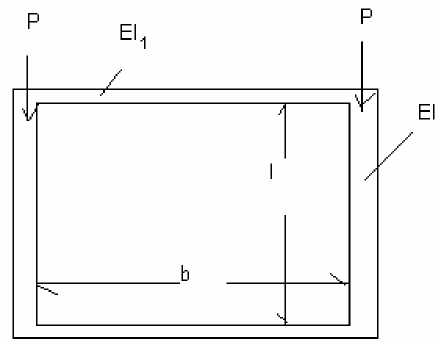
where

$$I = \frac{t^3}{12} = \frac{0.0787^3}{12} = 0.00004062$$

$$I_1 = \frac{t^3}{12} = \frac{0.03935^3}{12} = 0.000005077$$

$$b = 4.5cm = 1.771''$$

$$l = 3.8cm = 1.496''$$



Then, equation (b) becomes

$$\frac{\tan u}{u} = -6.775$$

and solve it for u with a lowest root. It gives

$$u = 1.66$$

and substitute into

$$k = \frac{2 * u}{l}$$

$$Pcr = k^2 * E * I$$

Then , the collapsing force Pcr can be found

$$P_{cr} = k^2 EI = \frac{4*u^2*E*I}{l^2} = \frac{4*1.66^2*0.4e6*0.00004062}{1.496^2} = 80lbf\ /\ in$$

$$SF = \frac{Pcr}{P} = \frac{80}{22.35} = 3.57$$

The Ansys gives SF=3.3 based on eigenvalue method and SF=2.9 based on the non-linear large deflection approach. They all seem to be close.